A fully simulated laboratory for instrumentation and electronic measurements

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Abstract – *An educational laboratory SWILAB, useful to develop and carry out fully simulated experiences on instrumentation and electronic measurements by using instrumentation simulators is proposed. SWILAB, running on Windows 95 or superior, includes several instruments like waveform generators, analog and digital oscilloscopes, analog and digital voltmeters and a Device Under Test (circuit simulator), all designed in C++ language. The interfaces between the instruments and the user are like the actual ones and the control panels were designed with a real look (containing all the instrument displays, connectors and control knobs). Particular care was devoted to make actual the action-effect relationship between the knob setting and the command execution. The connections among the electronic instruments and between the instruments and the DUT (Device Under Test) is realized by a SW communication channel and is completely transparent to the user. The connection is performed simply by drag and drop techniques between the connectors to be linked. The virtual laboratory is now used by students of regular courses in several Italian universities and in distance learning courses, with an high satisfaction level and didactic effectiveness.*

Keywords – *Virtual instruments, Multimedia, Electronic circuits, Spice simulator, and Electronic measurement laboratory.*

I. INTRODUCTION

Hypermedia systems, generally based on the integration of media like texts, audio, video and animations, are deeply affecting the traditional ways of teaching and learning.

Many of the knowledge domains get an advantage out of these educational techniques, especially where the traditional media can cover and satisfy the learning aspects of that disciplines. In several branch of knowledge, however, the laboratory practice assumes high relevance to reach a good level of experience and qualifications.

That is the case of all the engineering fields where a laboratory activity is required to deeply understand theoretical subjects by making experiments. In these cases the hypermedia system takes advantage by a media with simulation capabilities that provides a good tool to improve the effectiveness of the learning process. Some years ago our institution was involved in activating distance learning courses, together with traditional ones, and it was decided to invest resources to develop an alternative solution, based on the new technologies offered by computer based training, to the classic laboratory that requires attendance by the students [1].

The subject concerning the study of electronic circuits and electronic instrumentation, where the laboratory activity is fundamental to get skill in understand the circuit behaviour by using various kinds of instruments and techniques, well lend oneself to be represented by a virtual world where simulated objects performs activities similar to the actual ones.

Two possible solutions were considered to break the time/distance constraint. The first one, described in a previous paper [2], is based on the modern instrumentation, equipped with computer interface remotely programmable. The idea was to realize a laboratory where the physical resources were simultaneously and remotely accessible to several users, sharing concurrently the same instrumentation in a sort of time sharing process, managed by a server and transparent to the users.

The second one is based on a laboratory where all the instruments are completely simulated together with the circuit to be analyzed and tested. This solution is more agile of the previous one since doesn't require network connections and it can be completely fulfilled with computer local resources.

The second approach is the subject of this paper. The work, began several years ago, is in continuous development with the contribution of several students degree thesis.

The manuscript is organized in three sections. In the first one we describe briefly the software architecture of the laboratory and the main characteristics of each instrument. In the second section we present two examples illustrating the laboratory capabilities. Finally, the third section is devoted to the conclusions.

II. SYSTEM DESCRIPTION

In this section we will describe the software communication channels that allow the exchange of information among the instruments, and the main characteristics of the laboratory instruments. We will focus on the DUT that allows us to define the electronic circuit architecture by using SPICE paradigm.

A. Software architecture

Some details of the software architecture, useful for a deeper system understanding are here provided.

SWILAB includes a series of instrument simulators (analog generator, analog oscilloscope, digital oscilloscope and so on...) realized as executable programs. The main software structure can be outlined in the block diagram described in Figure 1 where:

➤ SWIFCL (SoftWare Instruments Foundation Class Library) is a static library that should be used by each

virtual instrument, when the Microsoft Visual C++ is adopted as software development tool, to make easier the instrument implementation. This library includes a class interface that simplifies the management of the SWIML functions and, in automatic and transparent way, the connection with DLL by means of an access to the registry.

➢ SWIML (SoftWare Instrument Manager Library) manages the type of the port involved in the communication channel and the control of correct port connection (related to the port type). We decided to implement such software as a "Dynamic library" (DLL), so that it can be independent of the instrument simulators. The communication management among these applications is entrusted to a SWIML component that handles the data transfer and the service information among the instruments and their synchronization. The communication model is realized following the schematic of Figure 2 and includes two port types:

- OUT port, used when the instrument provides an output signal to one or more instruments (for example an analog signal generator). The numerically coded signal is sent together with several other information describing the message characteristics (sampling frequency, number of points and so on ..)
- INPUT port, used when the instrument is addressee of an entering signal (for example an input port of the oscilloscope). In that case some information are required to the corresponding output connected port in order to inform the SW about the characteristics of the signal accepted by the instrument.

Figure 1: Block diagram of the system software architecture

➢ SWICML (SoftWare Instruments Communication Manager Library) is a static library, that performs the management of the shared memory where are stored the information of the virtual instruments registered in the system, the active instruments instances (logical instruments) and the related ports. All the connections between two logical instruments ports and the data write/read operation on the connection channel are also managed.

Other SW components are also realized in order to make easier the instrument development, for example dial .ocx (that realizes the instrument knob), port .ocx (that realizes the BNC connector), and so on.

By the user point of view the connection between two ports (that means creating a communication channel) can be made also by drag and drop one of the selected connectors to the other one. SWIML prevents two not compatible ports from making a bad connection.
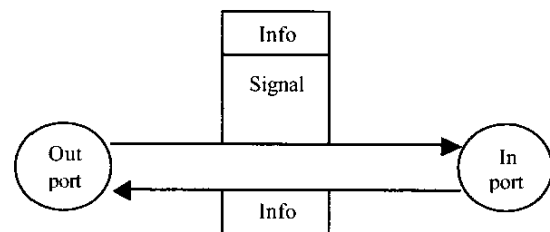

Figure 2: Model of the communication channel

B. Virtual laboratory's instruments

The virtual laboratory consists of several instruments like waveform generators, analog and digital oscilloscopes, analog and digital voltmeters and a DUT. The main goal in the design of user-interface application was to present instruments with capabilities similar to that of real instruments. The panels of the digital oscilloscope, waveform generator and DUT are shown in Figure 3, 4 and 5, respectively.

The DUT allows us to describe complex electronic circuits through the SPICE language. SPICE is a general-purpose circuit simulation program for nonlinear dc, nonlinear transient, and linear ac analyses. Circuits may contain resistors capacitors, inductors, independent current and voltage sources, four types of dependent sources, and the most common semiconductor devices.

In order to explain the circuital description of an electronic system, three input files should be provided to the DUT. They are the following:
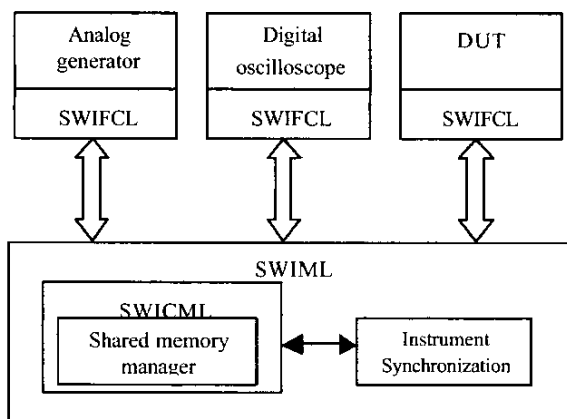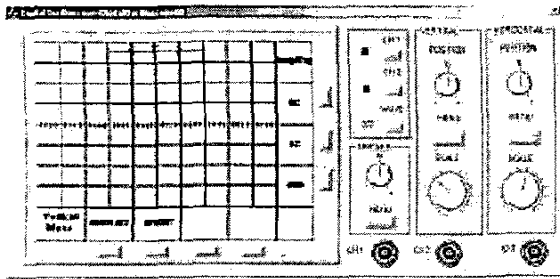
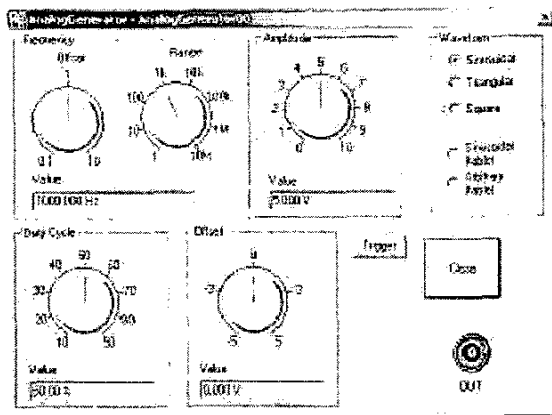Figure 3: Graphical interface of the digital oscilloscope

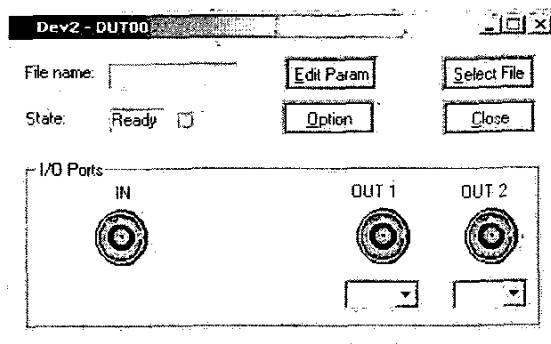Figure 4: Graphical interface of the waveform generator

Figure 5: Graphical interface of the Device Under Test

- The file *.inp must be constructed using the SPICE language rules. The circuit to be analyzed is described by a set of element lines, which define the circuit topology and a set of control lines, which define the control parameters and the run control. The first line in the input file must be the title and the last line must be ".END". The order of the remaining lines is arbitrary. Each element in the circuit is specified by an element line that contains the element name, the circuit nodes to which the element is connected, and the values of parameters that determine the electrical characteristic of the element. The input must be always a voltage source

connected between the node 1 and the ground node 0.

- The file *.prm allows to change the value to a set of electrical elements, without modifying the input file. It must contain in the first line the number of elements that change value and in the remaining lines the name and the new electrical value of the elements.
- The file *.wmf has a picture of the electronic system. This picture can be generated with a graphic tool that allows saving in the Windows Meta File format.

The files *.prm and *.wmf are optional.

III. EXAMPLES

In this section we present two examples where the waveform generator is directly connected to the DUT containing the circuit description. The outputs are displayed by using the digital oscilloscope and a vector voltmeter.

```
Example 1: BJT Amplifier
RC 4 3 5k
RB 1 2 10k
RE 5 0 1k
VCC 4 0 DC 10
Q1 3 2 5 Q2N2222A
.INCLUDE eval.lib
V1 1 0
.TRAN
.END
```
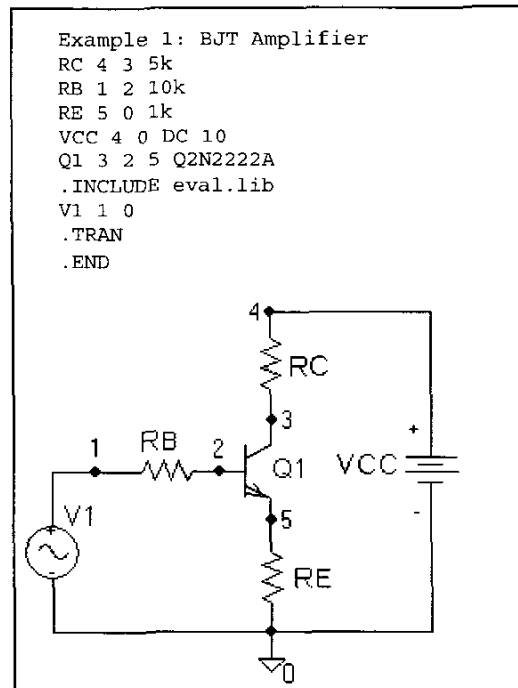

Figure 6: Emitter-common transistor amplifier description and circuit topology.

In the first experiment let us consider the transistor amplifier, topology simple and widely-used for a single stage, shown in Figure 6. In the figure it is also shown the description circuit file.

The input voltage source, connected between the nodes 1 and 0, provided by the analog generator, is a sinusoidal waveform with a DC offset for biasing purposes. That allows to easily setting the BJT operating point and ranging it from the transistor cut off to the saturation region. In particular Figure 7 shows input and output waveforms, i.e. the voltages at the nodes 1 and 3 when the BJT operates in the active region in small signal conditions.

The waveforms are displayed by the two channels digital oscilloscope connected to the corresponding circuit nodes.
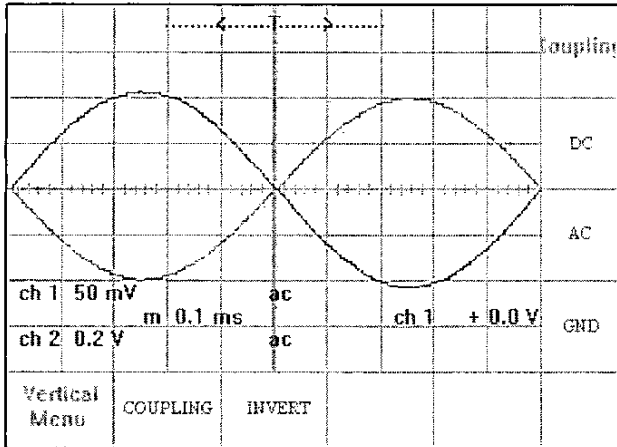

Figure 7: Digital Oscilloscope displaying the voltages to the node 1 (input signal) and node 3 (output signal) for the circuit of Figure 6

Figure 8 presents an analysis of the same circuit carried out by means of the vector voltmeter at higher signal frequency. The two voltmeter channels, A and B, connected respectively to the nodes 1 and 3, allow a direct measurement of the circuit response in amplitude and phase shift versus the frequency.
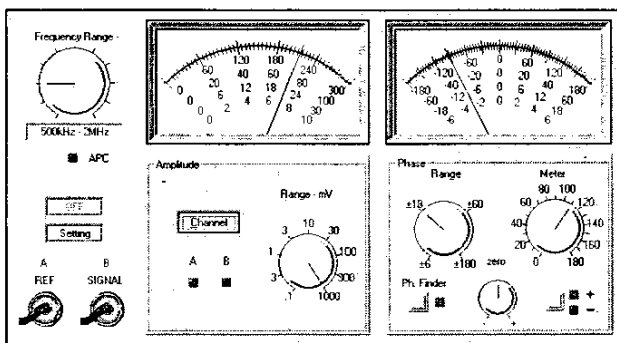

Figure 8: Vector voltmeter presentation of the voltages measured to the node 1 (input signal) and node 3 (output signal) and their phase shift

As second example let us examine the circuit of Figure 8 containing the μA 741 OP AMP connected as an inverting amplifier.

```
• An example of how to use an opamp model
.INCLUDE UA741.lib
Vcc 4 0 12V
Vee 5 0 -12V
* define an op amp
XOA 0 2 4 5 3 UA741
R1 1 2 10k
R2 2 3 10k
V1 1 0
.TRAN
.END
```
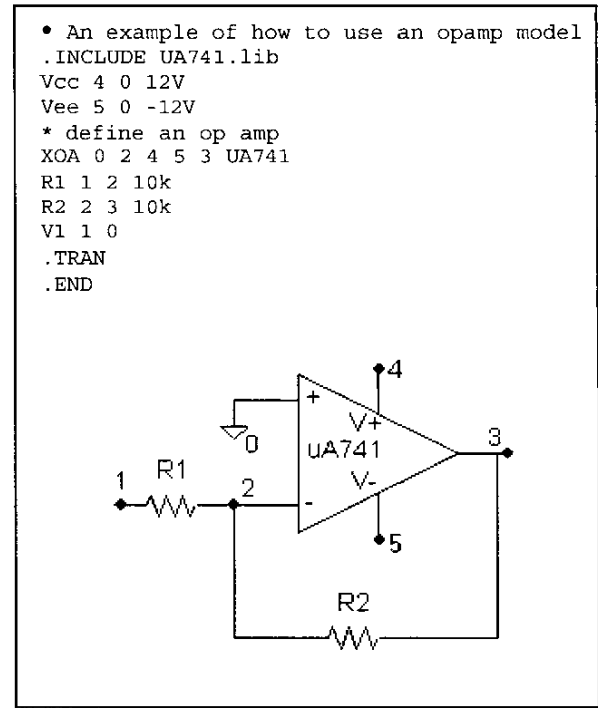

Figure 9: OP AMP circuit and its description by the file .inp

The circuit response is analyzed by means of the analog oscilloscope as shown in Figure 10.
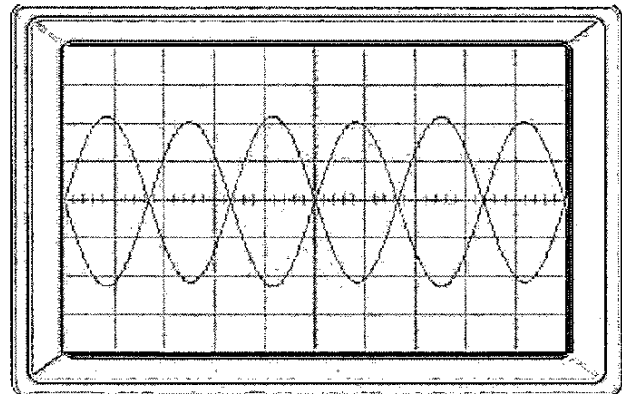

Figure 10: Analog Oscilloscope displaying the voltages to the node 1 (input signal) and node 3 (output signal) for the circuit of Figure 9

The OP AMP model is available in PSpice libraries and the used one is reported in Figure 11.

```
.subckt UA741 1 2 3 4 5
c1 11 12 4.664E-12
c2 6 7 20.00E-12
dc 5 53 dx
de 54 5 dx
dlp 90 91 dx
dln 92 90 dx
dp 4 3 dx
egnd1 98 0 3 0 0.500000
egnd2 99 98 4 0 0.500000
fb1 7 99 vb 10610000.000000
fb2 7 99 vc -10000000.000000
fb3 7 99 ve 10000000.000000
fb4 7 99 vlp 10000000.000000
fb5 7 99 vln -10000000.000000
ga 6 0 11 12 137.7E-6
gcm 0 6 10 99 2.574E-9
iee 10 4 dc 10.16E-6
hlim 90 0 vlim 1K
q1 11 2 13 qx
q2 12 1 14 qx
r2 6 9 100.0E3
rc1 3 11 7.957E3
rc2 3 12 7.957E3
re1 13 10 2.740E3
re2 14 10 2.740E3
ree 10 99 19.69E6
ro1 8 5 150
ro2 7 99 150
rp 3 4 18.11E3
vb 9 0 dc 0
vc 3 53 dc 2.600
ve 54 4 dc 2.600
vlim 7 8 dc 0
vlp 91 0 dc 25
vln 0 92 dc 25
.model dx D(Is=800.0E-18)
.model qx NPN(Is=800.0E-18 Bf=62.50)
.ends
```

Figure 11: PSpice OP AMP Model

SWILAB includes several examples, provided with the installation of the software, but each user can very easily built other circuits described by means of files like PSPICE input files. In order to complete the DUT is also useful to provide a circuit drawing carried out by means of a commune drawing software. SWILAB is a freeware software for didactics developed by financial support or the Politecnico di Torino and can be downloaded at the address: http://ladispe.eln.polito.it/swilab

IV. CONCLUSIONS

A system that simulates a complete laboratory which allows to perform didactic experiences on basic electronic circuits by means of virtual instruments is proposed. SWILAB is made up of a complete set of electronic instrument simulators and a box, provided by several access ports, that includes an electronic circuit (Device Under Test). The circuit can be easily described and modified by an input SPICE file and the whole simulation procedure is transparent to the user, making simple to produce new exercises and

verify the circuit response under different drive signal and configurations. SWILAB was proposed as an useful training tool to several student classes in traditional and in distance learning engineering courses.

SWILAB however should be considered not as a complete replacement of the actual laboratory experience, but rather as very good teaching aid to make softer the impact of the students with the real world.

In distance learning, where the students cannot attend the school laboratory, SWILAB can be also considered as a replacement of the laboratory activity, since however it gives to the student a good sense of the reality. By a programmed training with a series of exercises of increasing complexity, several practical situations can be evidenced. That induces the student to focus problems which cannot be discovered only by a theoretical approach, but, more effectively, by quickly verifying the circuit behaviour without using hardware tools.

The students have shown a good appreciation of the virtual approach to the electronic instrumentation and to the circuit analysis. Test examination on traditional students e/o distance learning classes, evidence that the students acquire in a short time a good confidence in understanding the electronic circuit analysis and in handling the electronic test instruments.

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